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Modelling the impact of climate and land cover change on hydrology and water quality in a forest watershed in the Basque Country (Northern Spain)

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ABSTRACT

The separate and combined effects of climate change and forest clearcutting on discharge, suspended particulate matter (SPM) and particulate organic carbon (POC) load at a seasonal and annual scale were evaluated for the Oka catchment.

Compared to the baseline scenario (1970–2000), climate change displayed a decrease in annual rainfall (RCP4.5: 27% and RCP8.5: 28%) and an increase in mean temperature (12% for both emission scenarios). Together with the decrease in rainfall, a decrease in discharge and, consequently, in SPM and POC load was also displayed. In RCP4.5, annual discharge, SPM and POC load decreased by 16%, 68% and 38%, respectively. A slightly larger decrease was found in RCP8.5: 21% for discharge, 70% for SPM load and 41% for POC load. Evapotranspiration (ET) increased relative to the baseline, with a change of 15% (RCP4.5) and 16% (RCP8.5).

With regard to forest clearcut scenarios, annual discharge ranged between 3% (Scenario 1) and 15% (Scenario 3). At the same time, ET decreased by between 2% (Scenario 1) and 13% (Scenario 3) relative to the baseline (2001–2012). The model predicted a rise in SPM load of between 19% (Scenario 1) and 106% (Scenario 3). The predicted annual POC load ranged between 9% (Scenario 1) and 47% (Scenario 3).

The combination of climate change and forest clearcutting scenarios showed a reduction in discharge, SPM and POC load compared to the baseline. Discharge, SPM and POC load decrease ranged between 2–18%, 30–63% and 12–36% in scenarios 8 and 7, respectively.

1. Introduction

Changes in climate and land cover are two main drivers affecting watershed hydrologic processes (Chien et al., 2013). These factors will affect the functioning of the ecosystem service of catchments, such as water provisioning and erosion control.

The Iberian Peninsula is recognized as one of the regions in the world most affected by climate change (IPCC, 2007). The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) points to projected changes to both hydrological and sediment response of catchments due to future shifts in precipitation and temperature regimes. Other forecast impacts include an increase in extreme phenomena, such as droughts, heatwaves, heavy rainfall, floods and fires. In most climate models, water availability from rivers is expected to decrease as a result of lower rainfall, higher soil water deficit and greater evapotranspiration (Molina-Navarro et al., 2014; IPCC, 2013; Nunes et al., 2008). The expected effects on soil erosion are linked to rainfall amount and intensity, soil water content and land cover (García-Ruíz et al., 2013).

This study uses new climate scenarios, the RCPs proposed by AR5. It seems apparent that very few hydro-sedimentary modelling studies have been conducted in the Oka catchment with regard to climate change impact assessment and no research using the new RCP scenarios. In this context, precipitation and temperature data from three CMIP5 GCM's, two downscaling methods and two RCPs were introduced into the SWAT model to evaluate the impact of climate change. As has been recognized, an ensemble of different scenarios gives more reliable results than a single-model simulation (IPCC, 2007).

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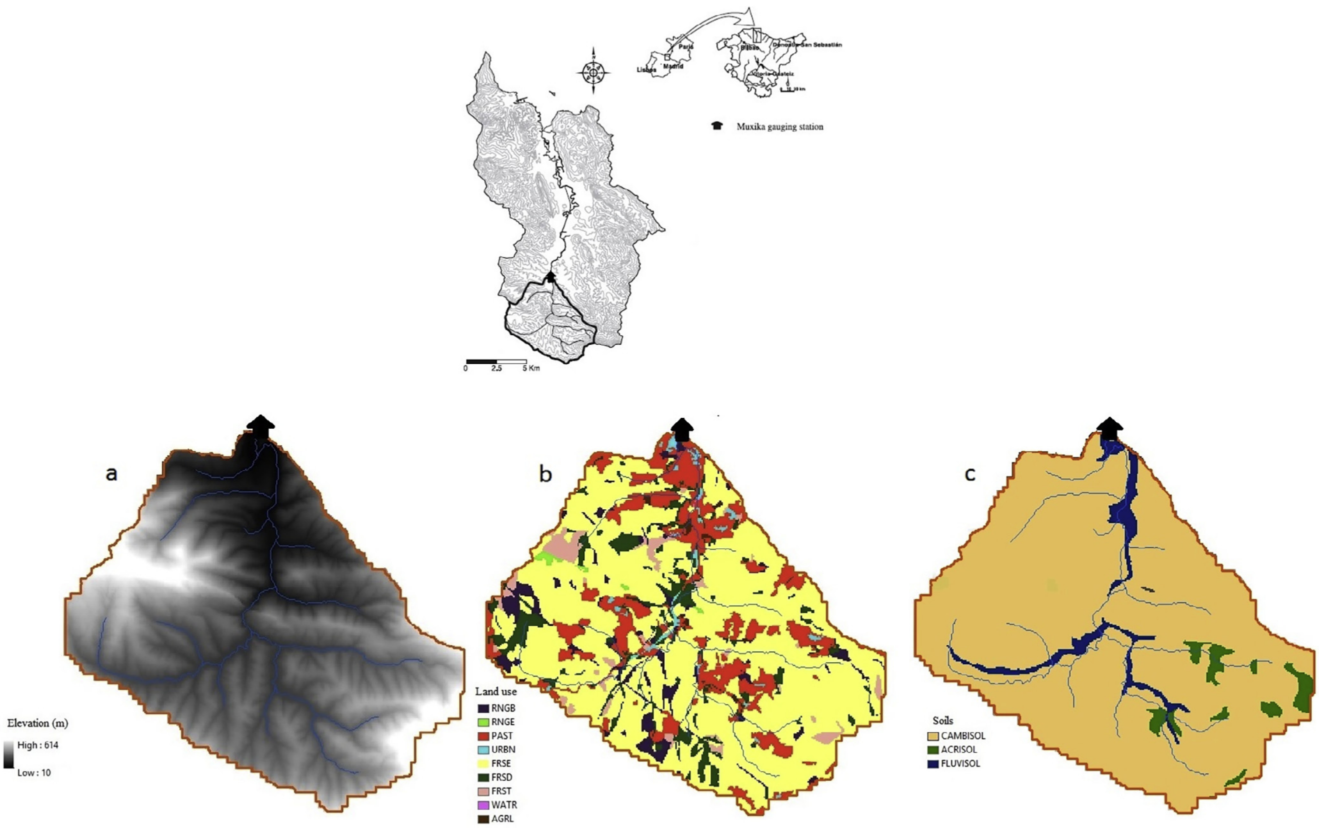

Fig. 1. Location, elevation, land use and soil types map of the Oka river catchment.

Land use changes affecting surface runoff, stream discharge and sediment export influenced by rainfall interception, evapotranspiration and surface soil hydraulic conductivity (Yan et al., 2013). Intensive forest management activities such as clearcutting may reduce surface water quality due to transportation of non-point source pollutants through surface runoff and sediments (Saleh et al., 2004).

The predominant land-use in the study area is forestry, and although autochthonous tree species have been promoted in recent years, in previous decades *Pinus radiata* and *Eucalyptus globulus* plantations were introduced throughout the region for timber and pulp. Forest management in these plantations involves clearcutting on rotations of even-aged stands along with mechanical site preparation for reforestation (i.e., scalping and down-slope ripping). Cutting and site preparation are the main drivers of land disturbance and sediment availability throughout the exotic tree plantations. These monoculture plantations of fast-growing evergreen species, together with the type of management applied, give rise to environmental problems, such as soil loss and compaction (Merino and Edeso, 1999; Merino et al., 2004), nutrient loss (Merino et al., 2004) and surface water turbidity caused by increased surface runoff (Garmendia et al., 2012). Therefore, in view of the economic importance of forest plantations in our study area and concern about water quality, an evaluation of the changes caused in water and erosion process following forest clearcutting seems essential to ensure sustainable timber extraction without altering catchment health.

While it is important to consider the individual effects of climate and land cover changes on hydrological and erosion processes, assessing how their combined effects will interact is crucial for any evaluation of the future status of water resources (Hoque et al., 2014; Li et al., 2012) and in order to provide a more realistic integrated assessment. For the Iberian Peninsula, only a few modelling studies have addressed the combined effects (e.g. Molina-Navarro et al., 2014; Carvalho-Santos et al., 2016b; Serpa et al., 2015). Most studies have focused on the separate effects of climate change or land cover (e.g. Pascual et al., 2015; Zabaleta et al., 2014; Meaurio et al., 2017; Nunes et al., 2011).

This study was performed in the Oka catchment (Basque Country, Northern Spain). Its aims were: (*i*) to evaluate the temporal transposability under contrasted climate conditions, in accordance with the differential split sampling; (*ii*) to assess the separate responses of discharge, SPM and POC export for forest clearcutting and climate change scenarios and (*iii*) to assess the effect of scenarios that combine changes in climate and forest clearcutting, on a seasonal and annual time step.

The Oka River watershed is important because it runs out into the Urdaibai estuary and is the main contributor of continental water and sediment to the estuary. In 1984, the estuary was designated a biosphere reserve by UNESCO (the Urdaibai Biosphere Reserve) on account of its ecological wealth.

This study provides useful information on the potential amount of discharge, SPM and POC load that may be produced under new Representative Concentration Pathways from CMIP5 in the Cantabrian region –an area that has been the subject of very little study– and forest clearcutting scenarios. It will be useful for managers and decision-makers in designing measures adapted to climate change and current trends in forest management, since forests are important carbon sinks and contribute to storing rainwater. It also provides long-term insights on organic carbon associated with SPM, which has been addressed little in studies of this kind.

2. Material and methods

2.1. Study area

The study area is located in the Oka Hydrographic. The study was conducted in the upper part (31.56 km^2) of the Oka river catchment (132 km^2) in the Urdaibai Biosphere Reserve in the province of Bizkaia,

Basque Country.

The catchment has steep slopes, averaging 26%. The main bedrock in the southern part of the catchment is an alternation of Tertiary sandy limestones, sandstones and lutites, while in the northern part it is Upper Cretaceous calcareous flysch with an alternation of marl and sandy limestone layers. Both Tertiary and Cretaceous formations are characterized by low permeability (EVE, 1996). The principal soils in the upper catchment are Humic Cambisols (90%) and Eutric Fluvisols in the near-stream areas Fig. 1c). This head catchment has been mostly reforested for industrial purposes with *Pinus radiata* and *Eucalyptus* sp. Autochthonous vegetation (*Quercus ilex*) occupies around 12% and farmlands only 7% (Fig. 1b).

The climate is temperate oceanic, as the catchment is located in the central Cantabrian region transition zone, between the Atlantic and Mediterranean climate zones. Annual mean temperature is 14 °C, with a minimum mean in January (8 °C) and a maximum mean in August (20 °C). Annual mean rainfall is 1205 mm (1999–2012), falling mainly in autumn and winter. The dry season is from June to September, although exceptionally high rainfall can occur. The hydrological regime is principally pluvial, with maximum water volume in November and low discharge during the summer (August and September). Mean recorded discharge at the Muxika gauging station from 1999 to 2012 was $0.64\ m^3\ s^{-1}$.

2.2. Field methodology

Discharge, precipitation, temperature and turbidity data were taken at the Muxika gauging station, which is owned by Bizkaia Provincial Council. All these data were measured once every 10 min from 1998 onwards.

The station comprises a crump profile single-crest weir. Turbidity was measured in the stream using a Solitax infrared backscattering turbidimeter with an expected range of 0–1000 NTU.

An automatic water sampler (SIGMA 900) was installed at the gauging station and programmed to start pumping 24 water samples of 800 mL when turbidity in the stream reached 100 NTU, to ensure monitoring of flood events. Pumping frequency was every two hours in all flood events.

Water samples were taken in polyethylene bottles and brought to the Chemical and Environmental Engineering Laboratory (University of Basque Country) to determine SPM and POC concentration. The laboratory determination of POC has been described in Peraza-Castro et al. (2016).

Continuous SPM time series were calculated from a good relationship between turbidity measured in the field and SPM measured in the laboratory (SPM = 0.9708 * NTU; $R^2 = 0.94$) (Peraza-Castro et al., 2015, 2016).

2.3. Estimating POC load by SWAT

To obtain continuous data for POC concentration, a regression equation was established with SPM measured during flood events (Peraza-Castro et al., 2016):

$$POC = 0.013*SPM + 1.44; \quad R^2 = 0.76$$

Once the simulated SPM was calibrated and validated satisfactorily, the long-term daily POC concentration could be computed from simulated SPM obtained from SWAT, using the above regression equation. This methodology has also been used by Oeurng et al. (2011) and Boithias et al (2014) in the Save river, France.

Observed and simulated annual loads of SPM and POC were estimated using Walling and Webb's method (Walling and Webb, 1985):

$$F = V*\sum_{i=1}^{n}(Qi\text{–}Ci)$$

where V (hm^3) is the annual water discharge; Ci ($mg\ L^{-1}$) is the SPM or POC concentration; Qi ($m^3\ s^{-1}$) is the instantaneous river water flow and n is the number of measurements.

2.4. Description of the hydrological model

The SWAT model is an agro-hydrological watershed-scale model developed by the USDA Agricultural Research Service (Arnold et al., 1998) to predict the impact of management practices on water, erosion and water quality. It is a physically based, semi-distributed, continuous-time model that can operate on daily, sub-daily, monthly and annual time steps and is able to predict the movement of water in complex watersheds with varying soils, land use and management conditions over long periods (Arnold et al., 1998; Neitsch et al., 2011).

The model divides the basin into sub-basins, which are then further divided into hydrological response units (HRUs) according to topography, land use and soil.

Surface runoff is estimated using the modified SCS curve number (USDA Soil Conservation Service, 1972). Peak runoff rate is calculated with a modified rational method (Chow et al., 1988). The flow is routed through channels using a variable storage method (Williams, 1969). Sediment yield was calculated using the Modified Universal Soil Loss Equation-MUSLE developed by Williams and Berndt (1977). Transport of the sediment through the channels is controlled simultaneously by deposition and degradation processes, which are determined by the sediment loads coming from upland areas and the transport capacity of the channel. A complete description of the theory and detail behind the different processes in the SWAT model can be found in Neitsch et al. (2011) and Arnold et al. (2011).

2.5. SWAT input data

The SWAT model requires input such as topography, soil, land use and meteorological data as described below:

- Digital elevation map (DEM) with a spatial resolution of 90 m × 90 m, from NASA. The model delineates the catchment and generates sub-basins and HRUs based on the DEM. In this case, the Oka River watershed was discretised into 23 sub-basins and 260 HRUs. It also provides topographic parameters such as slope, which is classified into three ranges: 0–5%, 5–20% and > 20% (Fig. 1a).
- Land use data at a scale of 1:10000 from the forest inventory of the Autonomous Community of the Basque Country (Geographical data base of the Basque Government, 2005). Use of the basin is mainly distributed between forest-evergreen (FRSE = 66%), pasture (PAST = 16%), forest-deciduous (FRSD = 8%), range-brush (RNGB = 5%), forest-mixed (FRST = 3%), agricultural land (AGRL = 1%) and residential (URBN = 1%) (Fig. 1b).
- Soil data at a scale of 1:25.000 from (Geographical data base of the Basque Government, 2005). Soil classes are simplified using the characteristics of the dominant soils. Soils are predominantly Humic Cambisols (92%), Acrisols (3%) and Eutric Fluvisols (5%) in the near-stream areas. Soil properties were obtained from the geographical database published by the Basque government (Fig. 1c).
- Meteorological data such as maximum and minimum temperatures and daily precipitation during hydrological years 2001–2015 were obtained from the Muxika gauging station (C063) owned by the Basque Meteorological Agency (www.euskalmet.eus) (Fig. 1). Hargreaves equation was selected for ET computation, since the available data are precipitation and maximum and minimum temperature.

2.6. Robustness for climatic transposability

In the context of climate change, the temporal transposability of model parameters identified during the calibration step must be

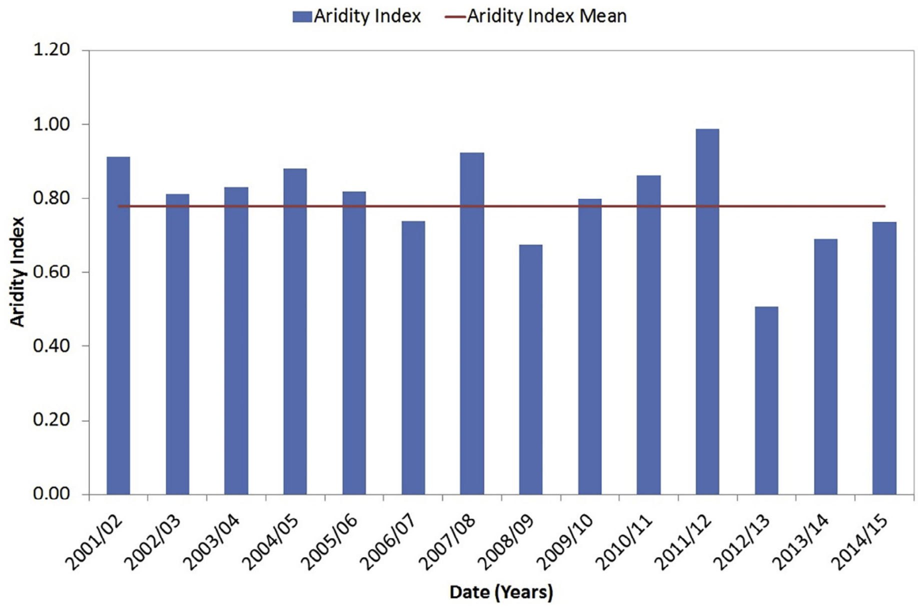

Fig. 2. AI for entire period of study 2001/02 to 2014/15.

assessed in a meaningful way and using an appropriate method of validation. A differential split-sampling test (DSST) (Klemeš, 1986) was used to assess model robustness in climate terms. This consists of separating the available period into two or more independent sub-periods with dissimilar climate characteristics and applying a cross-validation procedure between the sub-periods selected. In this case, the "Aridity Index" (AI) was chosen to identify the driest and wettest years during 2001–2015. The aridity index is calculated as the ratio between potential evapotranspiration and precipitation (Görgen et al., 2010; Brigode et al., 2013). As proposed by Brigode et al. (2013), the three consecutive driest and wettest years were chosen to assess whether the model is capable of correctly simulating contrasted conditions. Fig. 2 shows the three consecutive hydrological years with the lowest AI (2012/13, 2013/14, 2014/15) and the highest AI (2009/10, 2010/11, 2011/12). Thus, the DSST was constructed based on two contrasting three-year periods: a dry one extending from 2009 to 2012 and a wet one from 2012 to 2015.

For both periods, a calibration procedure was performed (see next section) on one period, followed by cross-validation on the other, using the same topographic, soil and land use data (Table 1).

2.7. Model calibration, validation and performance evaluation

The Oka River catchment model was previously calibrated and validated for discharge and SPM (concentration and load) during the period 2001–2012 on a daily scale. Further details on model configuration and hydro-sedimentary performance can be found in Peraza-Castro et al. (2015). In the present study, this SWAT application was expanded to quantify the potential land use and climate change impacts.

The calibration procedure described in Peraza-Castro et al. (2015) was applied in this work. A sensitivity analysis was performed to identify the most influential parameters for the model calibration using the Latin Hypercube One-At-a-Time (LH-OAT) approach offered in the SWAT-CUP. These parameters were related to base flow, surface runoff and erosion. The sensitive parameters and their calibrated values are listed in Peraza-Castro et al. (2015).

Table 1
DSST on climatic data.

Project	Calibration period	Validation period
Dry to Wet	2009–2012 (Dry)	2012–2015 (Wet)
Wet to Dry	2012–2015 (Wet)	2009–2012 (Dry)

As shown in Table 1, the model was calibrated twice. To verify the temporal robustness of the model through DSST, the following efficiency criteria were applied to discharge and SPM simulation at a daily time step: the coefficient of determination (R^2), the Nash-Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970) and the index of agreement (*d*) (Willmot, 1981, 1984).

The model's simulation performance is classified in accordance with Parajuli et al. (2009): excellent > 0.90, very good 0.75–0.89, good 0.50–0.74, fair 0.25–0.49, poor 0.00–0.24 and unsatisfactory < 0.00.

2.8. Design of scenarios

In this study, three different simulation scenarios (land cover change only, climate change only and land cover and climate change combined) were established to assess the separate and combined impacts on discharge, SPM and POC loads. The model was run at a daily step and the outputs were then converted into seasonal and annual averages. In all scenarios, the seasonal and annual impact was quantified as the percentage of change (%) between the baseline and the forest cutting and/or climate change scenario.

2.8.1. Forest clearcutting scenarios

The previously calibrated and validated SWAT model was used as a baseline to assess the effects of implementing forest clearcutting on discharge, SPM and POC load. The calibrated parameters, meteorological and soil data used for the baseline simulation were also used for the three scenarios to provide a consistent basis for comparison between the baseline and these land use change scenarios for the simulation period of 2001–2012, the time period used for the baseline model testing.

Three hypothetical forest clearcutting scenarios were proposed, based on current management of forest crops in the Urdaibai Biosphere Reserve, where most timberlands consist of exotic *Pinus radiata* and *Eucalyptus* plantations, primarily for timber and pulp (Rodríguez-Loinaz et al., 2013). For these, only FRSE and FRST were considered in construction of the scenarios, corresponding to 69% (~22 km^2) of the total area of the catchment). The scenarios are indicated in Table 2.

Baseline simulation was the calibrated and validated model

Table 2
Forest clearcutting scenarios.

Forest clearcutting scenario	Percentage of the total forest area is clearcut
1	10
2	25
3	50

(2001–2012). Classes were manipulated using the same land use map (2005). In all scenarios, the pasture, range-brush, urban and agricultural areas in the current landscape were left unchanged.

2.8.2. Climate change scenarios

Simulations with the previously calibrated and validated SWAT model were used to assess the potential long-term effects on discharge, SPM and POC loads resulting from future climate change projections. A study of the impact of global climate change on hydrological systems requires scenarios of future temperature and precipitation changes as input to the hydrological model. During our scenario simulations, it was assumed that there would be no changes in land use. The latest climate change projections (from CMIP5), provided by the Spanish Meteorology Agency (AEMET), were used in this study.

Direct application of output from general circulation models (GCMs) is often inadequate for hydrological assessments due to the coarse resolution of the GCM data, especially for precipitation. In order to mitigate the problem of spatial resolution, AEMET has downscaled some GCMs for the Coupled Model Intercomparison Project Phase 5 (CMIP5) using statistical techniques, applying two types of empirical algorithms based on analogous techniques (AN) (Petisco and Martín, 2006) and linear regressions (SDSM) (Wilby et al., 2002).

CMIP5 identifies four mitigation scenarios, called RCP. The numbers in the CMIP5 scenarios represent the predicted amount of radiative forcing by 2100. In this study two emission scenarios were used: RCP8.5 is the high emission scenario characterized by increasing greenhouse gas emissions with radiative forcing in 2100 of 8.5 $W\,m^{-2}$ and RCP4.5 is a medium mitigation scenario whose radiative forcing is stabilized before 2100 at 4.5 $W\,m^{-2}$ through the use of a range of technologies and strategies to reduce greenhouse gas emissions (Moss et al., 2010; Taylor et al., 2012). In 2100, total anthropogenic radiative forcing was 2.29 $W\,m^{-2}$ relative to 1750 (IPCC, 2013).

Daily precipitation and maximum and minimum temperatures from the baseline period (1970–2000) and future climate projections (2011–2050) were provided by AEMET for a meteorological station (1075E) located approximately 17 km from the Muxika gauging station.

This SWAT project was forced with an ensemble of 3 GCMs (BNU_ESM, MPI_ESM_MR and MIROC_ESM), 2 RCPs (8.5 and 4.5) and 2 downscaling methods (AN and SDSM). Thus, the SWAT was run six times. Table 3 shows the climate projections used in this study.

The climate projection baselines (1970–2000) of the 3 GCMs (downscaled with AN and SDSM methods) were compared to the data observed at meteorological stations of the studied area, selecting those that best fitted (Meaurio et al., 2017)

Table 3
GCM, institution, country, downscaling method and RCP.

GCM name	Institution	Country	Downscaling method	RCP
BNU_ESM	College of Global Change and Earth System Science	China	SDSM	4.5 8.5
MPI_ESM_MR	Max-Planck-Institut fur Meteorologie	Germany	SDSM	4.5 8.5
MIROC_ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute and National Institute for Environmental Studies	Japan	AEMET analogue	4.5 8.5

2.8.2.1. Bias correction

2.8.2.1. Bias correction. Bias correction is needed to remove bias between model and observations at basin level, since GCMs usually have poor spatial resolution and if they are introduced directly into hydrological models, the performance is poor (Fowler et al., 2007). For each GCM, the variables of precipitation and maximum and minimum temperatures were subjected to a linear scaling approach for bias correction (Lenderink et al., 2007) due to differences between observed measurements and projected baselines. This approach applied monthly correction factors to daily-modelled time series of the given month. The values for each month are adjusted with the same correction factor (Teutschbein et al., 2013) and this factor is time independent. This method preserves the trend while adjusting the mean value (Hempel et al., 2013). Correction factors were determined as differences (temperatures) or quotients (precipitation) between the long-term mean of observed and GCM-projected baselines. The bias-corrected values were entered as input in the SWAT.

The linear-scaling approach of precipitation is defined as:

$$^{*}P_{CP}(d) = P_{CP}(d) * (P_{OBS\ MEAN}/P_{CP\ MEAN})$$

where

$^{*}P_{CP}(d)$ is the bias-corrected precipitation for the climate projection (future 2011 to 2050) in a daily time step.
$P_{CP}(d)$ is the precipitation for the climate projection (future 2011–2050) in a daily time step.
P_{OBS_MEAN} is the monthly mean observed precipitation (1970–2000).
P_{CP_MEAN} is the monthly mean precipitation for the climate projection (baseline 1970–2000).

And the linear-scaling approach of maximum and minimum temperature is defined as:

$$^{*}T_{CP}(d) = T_{CP}(d) + T_{OBS\_MEAN} - T_{CP\_MEAN}$$

where

$^{*}T_{CP}(d)$ is the bias-corrected temperature for the climate projection (future 2011–2050) in a daily time step.
T_{CP} is the temperature for the climate projection (future 2011–2050) in a daily time step.
T_{OBS_MEAN} is the monthly mean observed temperature (1970–2000).
T_{CP_MEAN} is the monthly mean temperature for the climate projection (baseline 1970–2000).

2.8.3. Combined scenarios

An integrated approach combining the impacts of climate change and land cover is crucial for a realistic assessment of the future state of freshwater resources. For this reason, four scenarios have been set out, taking into account the minimal (10%) and extreme (50%) forest clearcutting scenarios and the two emission scenarios (Table 4):

Table 4
Combined scenarios.

Combined scenario	Forest clearcutting scenario	Climate change scenario
6	10% of the total forest area is clearcut	ensemble RCP4.5
7	50% of the total forest area is clearcut	ensemble RCP8.5
8	10% of the total forest area is clearcut	ensemble RCP4.5
9	50% of the total forest area is clearcut	ensemble RCP8.5

- Scenario 6: 10% clearcut forest + ensemble RCP4.5
- Scenario 7: 10% clearcut forest + ensemble RCP8.5
- Scenario 8: 50% clearcut forest + ensemble RCP4.5
- Scenario 9: 50% clearcut forest + ensemble RCP8.5
- Baseline: 1970–2000 and current land use (map 2005), projections 2011–2050

3. Results and discussion

3.1. Robustness for climate transposability

To test the robustness to climate change, two periods with dissimilar climatic characteristics were used to calibrate and validate the SWAT model on the Oka catchment from a DSST perspective. After identifying the most sensitive parameters, the model was successively calibrated over a dry period and a wet period. The model was then validated against the opposite period.

The statistical criteria between observed and simulated discharge and SPM load indicate a satisfactory simulation during the calibration and validation period, in accordance with the classification by Parajuli et al. (2009). Almost all efficiency criteria values range between 0.50 and 0.93, except for some specific values of SPM concentration ranging between 0.36 and 0.45, which are acceptable values. Performance values obtained for both calibration/validation procedures are given in Table 5.

Validation values are slightly lower than calibration values. This trend was also observed by Grusson et al. (2017) in the Garonne River watershed. In a DSST, lower performance values in validation are expected. Robustness for climatic transposability may be confirmed when the performance difference is minimal, which was the case here. Thus, it can be concluded that the SWAT model is a valid tool for simulating the effects of climate changes.

3.2. Climate change impact on climate characteristics

The precipitation and temperature variations in a future climate were assessed by comparing the baseline data from 1970 to 2000 and projected precipitation and temperature series, which were estimated for 2011 to 2050 for each emission scenario (Fig. 3).

A general reduction in precipitation and a general increase in temperature is observed, which is slightly more accentuated in the less favourable scenario (RCP8.5) than in the lower-emissions one (RCP4.5). During the total baseline period, annual mean precipitation was 1430 mm and the RCP4.5 and RCP8.5 scenarios forecast an annual precipitation of 1050 mm and 1028 mm, respectively. Anticipated decreases in monthly precipitation in RCP4.5 oscillate between 8 and 39% with an annual decrease of 24%. A slightly higher reduction is expected for RCP8.5: 6–40% with an annual decrease of 27%. In both cases, these ranges were seen in July and November. Rainfall seasonality also varied; more marked changes occur in summer (RCP8.5 = 36% and RCP4.5 = 34%). The change during autumn is less (19% for both emission scenarios).

Monthly mean temperature ranged from 9.5 °C (January) to 23 °C (August) for both RCP4.5 and RCP8.5 scenarios. The annual mean temperature during the baseline period was 13.6 °C. There are small differences in change between emission scenarios; the annual percentage of change is 11% and 12% for the RCP4.5 and RCP8.5 scenarios, respectively. Relative to the baseline, there is an annual variation of ~1.6 °C for both scenarios (RCP4.5 = 15.1 °C and RCP8.5 = 15.2 °C). Summer and spring are the warmest seasons, but winter and autumn present the greatest percentage of change –11% and 14% under RCP4.5, and 12% and 15% under RCP8.5– indicating that the cold seasons will be warmer. In general terms, the RCP8.5 emission scenario is drier and warmer than RCP4.5.

3.3. Climate change impacts on discharge, SPM and POC load

The calibrated and validated model was run for three climate models in the 2011–2050 time frame (keeping land use conditions constant). The change in discharge and SPM and POC load were calculated with respect to the baseline period (1970–2000). Arithmetic mean ensembles of these climate models were analysed. Fig. 4 shows the changes in seasonal and annual scale for the future period under both emission scenarios.

Although there were slight differences between emission scenarios, seasonal variations predicted a decrease in discharge, SPM and POC load most markedly in summer and spring, followed by autumn and winter. The discharge, SPM and POC load in summer and winter decreased by 22–9%, 84–58% and 45–29%, respectively, in RCP4.5 and by 28–13%, 85–58% and 48–31% respectively, under RCP8.5. Major reductions in water discharge during the summer season, with minor flow in this basin may have important consequences for natural and agricultural ecosystem functions.

At an annual scale, in RCP4.5 the discharge, SPM and POC load decrease relative to the baseline by 16% (664 mm yr^{-1}), 68% (611 t yr^{-1}) and 38% (38 t yr^{-1}), respectively. A slightly larger decrease was seen in RCP8.5: 21% (626 mm yr^{-1}) for discharge, 70% (575 t yr^{-1}) for SPM load and 41% (35 t yr^{-1}) for POC load. These minor differences between RCP scenarios may be attributable to short-term projections, where expected changes are not very significant, since the majority of models anticipate the most substantial changes at the end of the century.

The general reduction in discharge is related to the decrease in precipitation forecast for both scenarios (Figs. 3 and 4) and ET increase (Table 6). These results concur with other studies conducted in the Iberian Peninsula (Carvalho-Santos et al., 2016a; Serpa et al., 2015; Zabaleta et al., 2014), which identified precipitation as the main cause of reduced surface water availability.

Table 5
Efficiency criteria obtained in calibration and validation for the two climatic DSSTs.

	Dry calibration (2009–2012)			Wet validation (2012–2015)		
	Discharge	SPM concentration	SPM load	Discharge	SPM concentration	SPM load
R^2	0.76	0.45	0.78	0.74	0.44	0.75
NSE	0.75	0.37	0.67	0.70	0.36	0.65
d	0.91	0.81	0.86	0.89	0.79	0.85
	Wet calibration (2012–2015)			**Dry validation (2009–2012)**		
	Discharge	SPM concentration	SPM load	Discharge	SPM concentration	SPM load
R^2	0.79	0.55	0.59	0.75	0.52	0.55
NSE	0.79	0.45	0.58	0.75	0.42	0.54
d	0.93	0.85	0.84	0.89	0.82	0.80

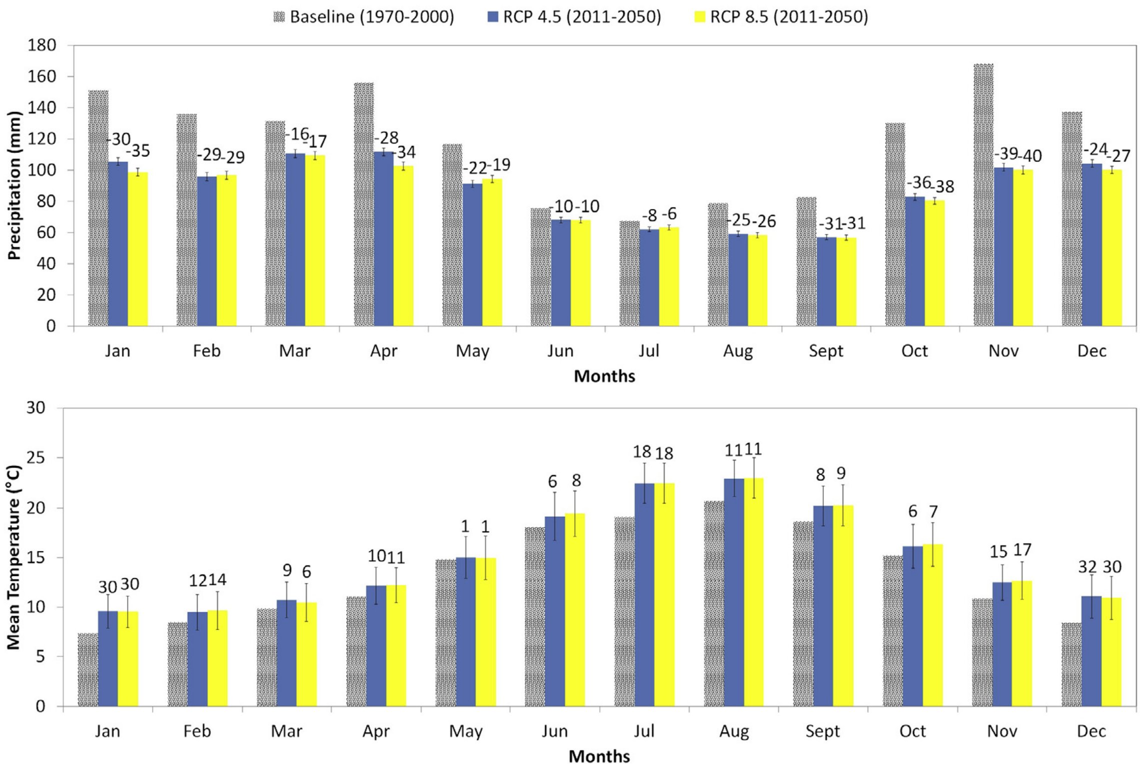

Fig. 3. Average monthly precipitation and temperature for baseline (1970–2000) and in RCP4.5 and RCP8.5 future emission scenarios (2011–2050). The numbers above each bar correspond to the percentage of change. Standard deviation bars are also indicated.

SPM and POC loads followed the same annual and seasonal patterns of precipitation, i.e. the wet season presents more discharge, SPM and POC load. Reduction in rainfall is generally linked to decreased runoff and soil erosion (Nunes et al., 2008; Serpa et al., 2015).

According to the AR5, frequency and intensity of heavy precipitations will increase in Southern Europe, resulting in further erosion during flood events. A later work could consider this impact at flood event level, since in annual terms its effect is not clearly observed and given that Peraza-Castro et al (2016) and Montoya-Armenta (2013) have concluded that most soil loss takes place in a small numbers of powerful erosive rainfall events in this catchment.

In the Oka catchment, the precipitation and water volume are strongly correlated to SPM and POC loads (Peraza-Castro et al., 2016; Montoya-Armenta, 2013). POC comes mainly from erosion; runoff washes off particles from the shallowest soil layers which have the greatest proportion of organic carbon. Thus, reduced POC is associated with a decrease in water discharge and SPM load. In a context of climate change, soil carbon stocks could be lost due to a higher rate of decomposition of organic matter in the soil resulting from increasing air temperatures.

The impact of climate changes on SPM, and hence POC load, can be greater than on discharge. The impact of climate change on erosion rates –and POC losses– can vary by catchment scale, type of land use and future climate conditions.

On the other hand, the combination of increase in temperature and decrease in precipitation results in an increase in ET, with a percentage change of 15% (RCP4.5) and 16% (RCP8.5) relative to the baseline (613 mm) (Table 6). ET increase implies a greater requirement for available water stored in the soil to satisfy vegetation needs.

This type of assessment has to deal with a cascade of uncertainties associated with different levels in the modelling procedure. This means that the uncertainties inherent to each of these levels accumulate the uncertainties of previous levels and all of them converge in hydrological models.

Under stable climate conditions and/or physical characteristics, errors in the model structure and calibration procedure are the main sources of uncertainty (Bastola et al., 2011; Brigode et al., 2013). In non-stationary conditions, such as those that occur under climate change, coarse resolution of the climate models, their representation of the atmospheric and other processes and differences in the results of downscaling techniques are key concerns (Braga et al., 2013; Chiew et al., 2010; Teng et al., 2012). Although the relative significance of the different sources of uncertainty has not often been quantified, studies have shown that uncertainties from GCM outputs are more significant than those from hydrological models (Arnell, 2011; Chen et al., 2011; Teng et al., 2012).

In this work, two emission scenarios (RCP4.5 "low-medium scenario" and RCP8.5 "high scenario"), three global climate models and two downscaling methods were considered. The RCPs selected were two contrasted emission scenarios, in order to consider a range of future storylines that reduce the associated uncertainty. The downscaling methods were validated by AEMET to improve the special resolution of GCMs. Because SWAT is a hydrological model broadly used for similar studies around the world, its usefulness as a tool for analysing the expected impact of climate change on quality and quantity of water resources is enhanced. In addition, a short term period (2011–2050) was selected to reduce the associated uncertainty with forecasts to the end of the century.

In order to reduce uncertainties, the assessment of impact ranges should be widened to take in a wider spectrum of climate projections. Simulations with data from more GCMs is needed to obtain a wider range of results and better assessment of potential impacts.

3.4. Forest clearcutting impacts on discharge, SPM and POC load

The effects of forest clearcutting on discharge, SPM and POC load were assessed by comparing model results from the three hypothetical scenarios and those from the baseline model. Comparisons of the seasonal and annual loads between baseline and hypothetical scenarios are shown in Fig. 5.

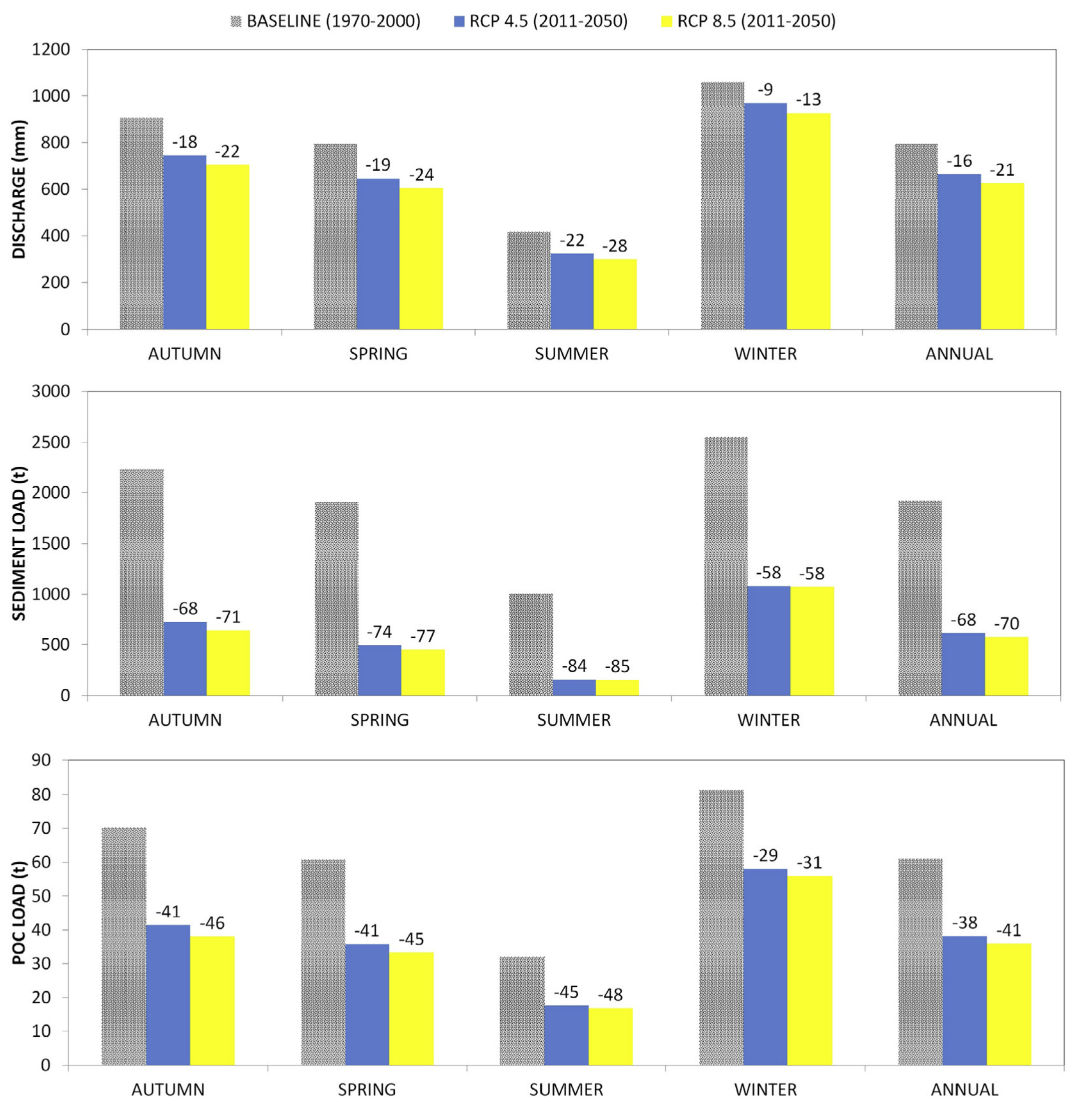

Fig. 4. Seasonal and annual average discharge, SPM and POC load in RCP4.5 and RCP8.5 emission scenarios. The number above each column shows the percentage of change.

Table 6
Average annual ET (mm yr^{-1}) for Oka catchment under climate change and forest clearcut.

Scenarios		ET
Climate change	Baseline	613
	RCP4.5	707
	RCP8.5	709
Forest clearcut	Baseline	618
	10%	602
	25%	578
	50%	537

At seasonal scale, the most abrupt changes in discharge, SPM and POC load occurred during summer and spring followed by autumn and winter. Discharge, SPM and POC load in summer and winter decreased by 4–2%, 27–14% and 12–6%, respectively, in Scenario 1; by 10–5%, 69–38% and 31–16% respectively, in Scenario 2; and by 21–10%, 144–79% and 63–34%, respectively, in Scenario 3.

Annual predicted discharge (mm yr^{-1}) was 588, 614 and 657 from the scenarios in which forest clearcutting was applied to 10%, 25% and 50%, respectively. Compared to the discharge baseline, there was an increase of 3% (Scenario 1), 8% (Scenario 2) and 15% (Scenario 3). At the same time, the decrease in ET relative to the baseline (618 mm) was 2% in Scenario 1, 6% in Scenario 2 and 13% in Scenario 3 (Table 4). This increase in discharge is caused by a reduction in ET from forest clearcut areas compared to the more effective ET from previously vegetated surface. Deep roots of forest plants can draw moisture from soil faster than water being transpired by sparse vegetation (Guo et al., 2008). The decrease in ET can be explained by a decrease in forested areas, which results in a decrease in the evaporation effect from leaves. Sparsely vegetated areas have lower transpiration and interception rates as compared to forested areas, i.e. the water is not intercepted by the vegetative surface where is it held and made available for evaporation.

The model predicted a rise in SPM load for the proposed scenarios. The annual percentage change is much larger than for discharge. This suggests that the impact of forest clearcutting is greater on SPM load than on discharge. The SPM load (t yr^{-1}) corresponding to each scenario was 1284 (Scenario 1), 1619 (Scenario 2) and 2214 (Scenario 3); representing a percentage of change from the baseline of 19%, 51% and 106%, respectively. The predicted SPM load yielded by the 50% forest clearcutting scenario is more than twice that yielded by the baseline scenario. As expected, the greatest amount of SPM was generated in this scenario. In general, forest clearcutting increases the amount of water available for surface runoff; therefore, increase in SPM load after

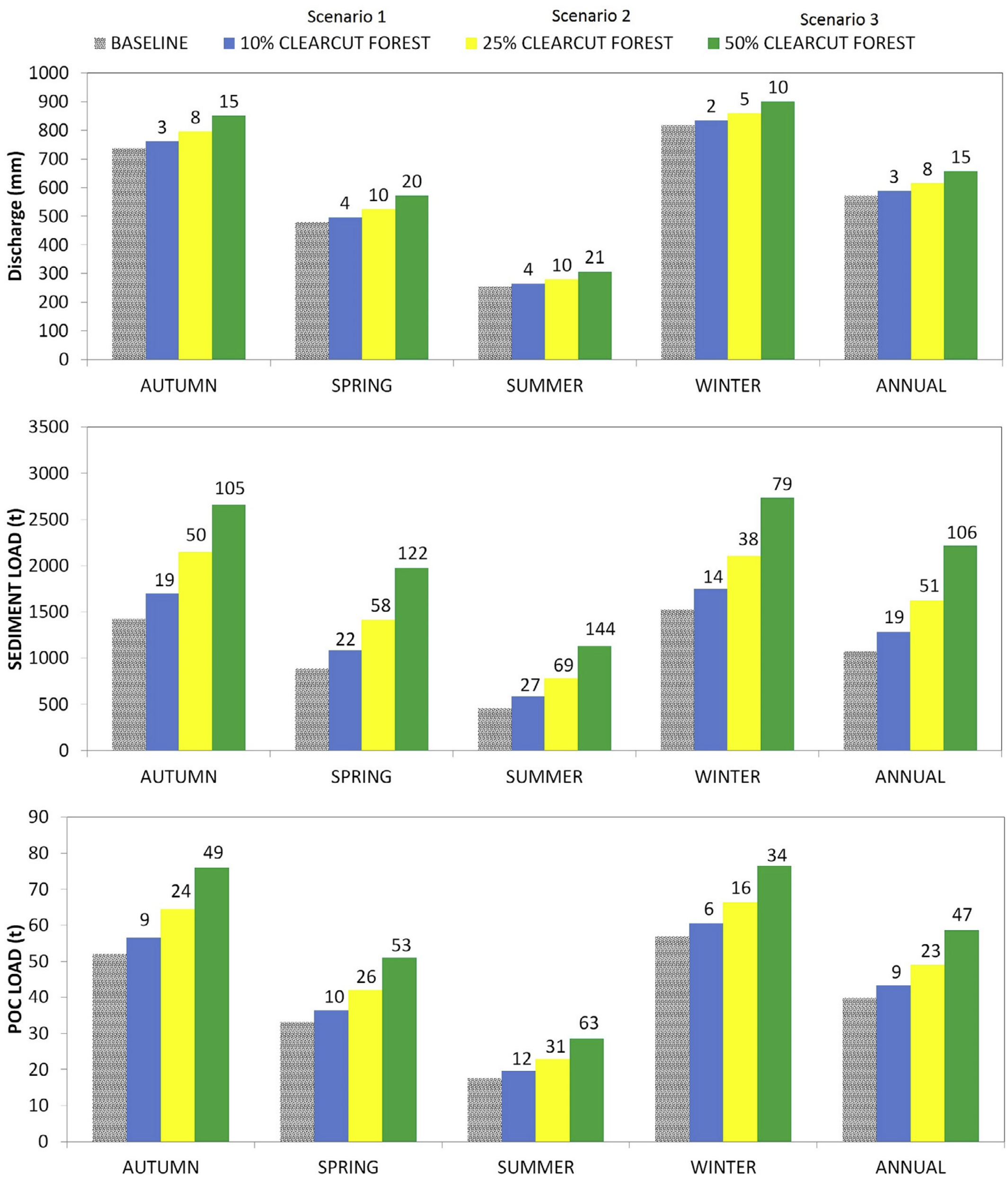

Fig. 5. Average seasonal and annual discharge, SPM and POC load in three forest clearcutting scenarios. The numbers above each column correspond to percentage of change.

clearcutting can be attributed to an increase in surface runoff.

With deforestation, the canopy storage is reduced and raindrops cannot be intercepted, thus increasing the erosive energy of droplets (Cerdan et al., 2010; Garcia-Ruiz et al., 2011). The soil is therefore saturated more easily and less rainfall infiltrates into the soil, with the result that much of the rainfall is transformed into runoff, generating soil erosion. These results concur with findings from a similar modelling exercise performed in a basin dominated by forest located in Mississippi (Khanal and Parajuli, 2013).

Forest clearcutting accelerates vegetation loss and exacerbates soil erosion. Deforestation gives rise to further erosion during flood events, providing a greater amount of sediment in coastal zones. In our case, the Oka River runs for just a few kilometres through the Urdaibai Estuary. The impact of an increase in SPM loads in estuaries may result in burying benthic communities and cause an increase in water turbidity, reducing light penetration and resulting in numerous adverse effects (Lozada et al., 2014).

Due to the negative impacts that exotic monocultures plantations have on the environmental, there is an urgent need to evaluate alternative trees species. Rodríguez-Loinaz et al. (2013) found that changing pine and eucalyptus plantations to native species plantations as *Q. robus* and *F. sylvatica* sequesters more carbon in the living biomass in the long-term while improving ecosystem services such as biodiversity conservations, water flow regulation and soil protection.

In the Basque Country, the main problem of timberland plantations is their impact on soils during clearcutting operations and soil preparation activities before planting. In these activities, the top layer of the soil is removed and left without vegetation, leading to major soil loss, as well as problems of river water turbidity (Rodríguez-Loinaz et al., 2013). In areas with high slopes and heavy precipitation –as in our case– these activities entail a loss of organic matter and an increase in water erosion (Edeso et al., 1998; Merino and Edeso, 1999).

The annual predicted POC load (t yr^{-1}) corresponding to each scenario was 43 (Scenario 1), 49 (Scenario 2) and 59 (Scenario 3);

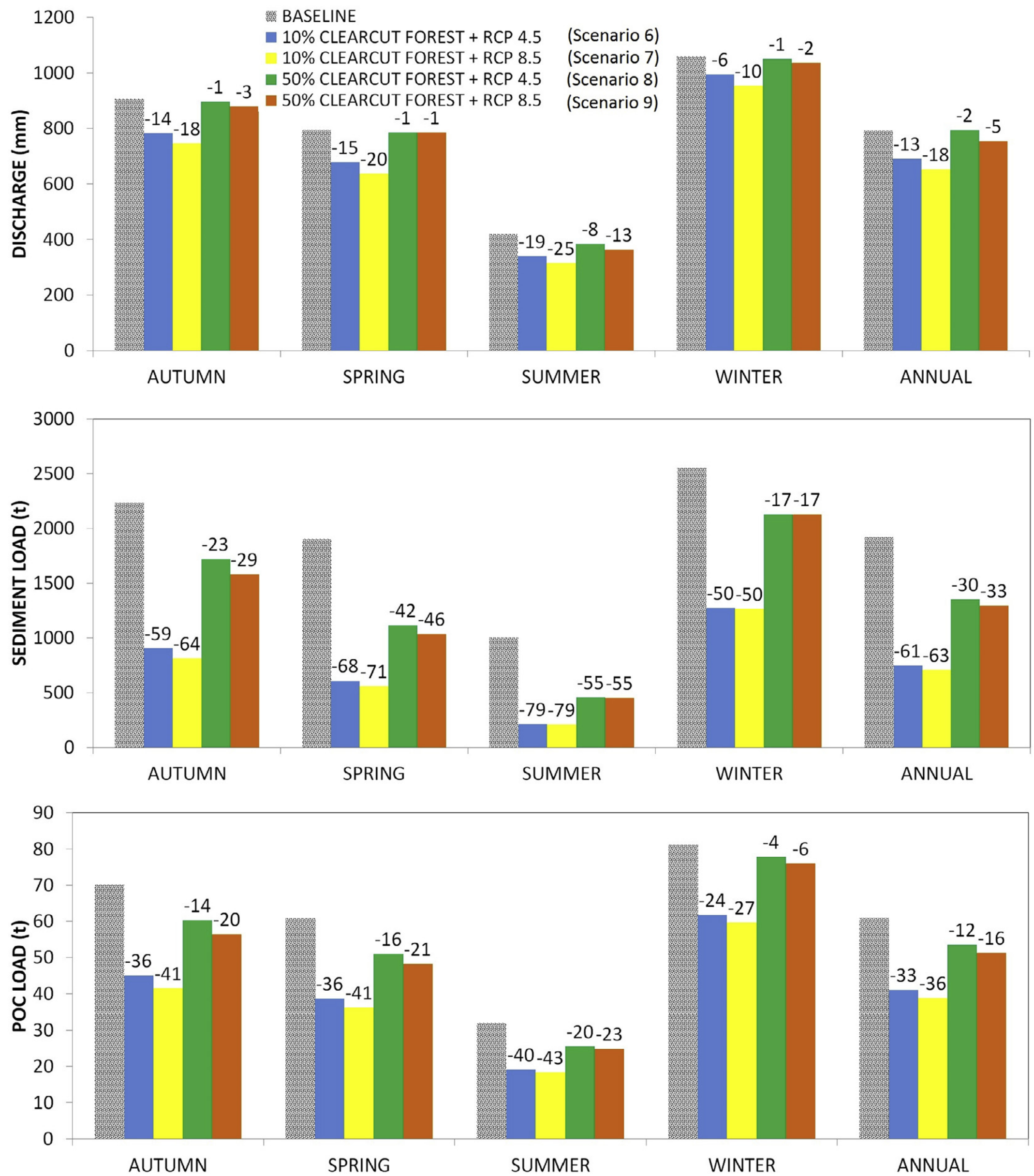

Fig. 6. Average seasonal and annual discharge, SPM and POC load under combined climate and forest clearcutting scenarios. The numbers above each column correspond to the percentage of change.

representing a percentage change of 9%, 23% and 47% from baseline, respectively. Because they are associated with particulate matter they follow the increasing trend of SPM; however, the change is less abrupt than for the SPM load. Forest clearcutting impoverishes the soil and leaves it unprotected against erosion. POC is highly influenced by the amount of sediment eroded, with the highest values corresponding to high SPM levels (Garcia-Aragon and Droppo, 2011). The increase in soil erosion resulting from forest cover loss entails the loss of organic carbon in the soil horizons richest in carbon. This not only means a loss in organic matter but also in the soil's mechanisms of physical protection. The loss in organic matter in the soil reduces water infiltration capacity, increasing runoff and erosion. Erosion in turn reduces the organic matter content by washing away fertile land (FAO, 2009).

3.5. Combined impacts of climate change and clearcutting on discharge, SPM and POC load

The combined impacts of future climate conditions and land cover were assessed using the climate projection ensemble and two forest clearcutting scenarios. The results of the model were compared to the baseline climate (1970–2000) and current land use (map 2005). Fig. 6 shows a comparison at seasonal and annual scale between baseline and proposed combined scenarios.

At seasonal scale, the most abrupt changes in discharge, SPM and POC load occurred during summer and spring followed by autumn and winter. Discharge, SPM and POC load in summer and winter decreased by 19–6%, 79–50% and 40–24%, respectively, in Scenario 6; by 25–10%, 79–50% and 43–27% respectively, in Scenario 7; by 8–1%, 55–17% and 20–4%, respectively, in Scenario 8 and by 13–2%, 55–17% and 23–6% respectively, in Scenario 9.

The annual predicted discharge (mm yr^{-1}) was 690, 952, 793 and 755 in scenarios 6, 7, 8 and 9, respectively. Compared to the discharge baseline there was a decrease of 13% (Scenario 6), 18% (Scenario 7), 2% (Scenario 8) and 5% (Scenario 9).

The annual predicted SPM load (t yr^{-1}) corresponding to each scenario was 748 (Scenario 6), 708 (Scenario 7), 1352 (Scenario 8) and

1296 (Scenario 9); representing a percentage of change of −61%, −63%, −30% and −33% from the baseline, respectively.

The annual predicted POC load (t yr^{-1}) was 41, 38, 53 and 51 in Scenarios 6, 7, 8 and 9, respectively. Compared to the baseline there was a decrease of 33% (Scenario 6), 36% (Scenario 7), 12% (Scenario 8) and 16% (Scenario 9).

All scenarios maintain climate change and forest cutting trends separate, i.e. an RCP8.5 emission scenario and 10% forest clearcutting scenario presented less discharge, SPM and POC load than an RCP4.5 and 50% forest clearcutting scenario. There are few differences between scenarios with the same percentage of forest clearcutting, i.e. 6 and 7, and Scenarios 8 and 9. However, Scenario 8 and Scenario 9 –corresponding to 50% of forest clearcut + RCP4.5 and RCP8.5– showed a minor reduction in all variables indicating that the impact of forest clearcutting for Scenarios 6 and 7 is more important than climate change.

In general, a decrease in discharge, SPM and POC load was observed with respect to baseline scenario. This downward trend is caused by the effect of climate change scenarios; however the percentage of change was not as severe as the effects separately, indicating compensation from the increase caused by forest clearcutting scenarios. The combined effect of climate change and forest clearcut can enhance or degrade the impacts on water production or SPM and organic carbon transport. In this case, there is a decrease in water discharge, considered as a negative effect, especially in summer. On the other hand, there is a positive impact in the reduction in soil loss and its associated-organic carbon.

In a climate change context, an increase in the number of intense rain episodes is projected, which together with the forestry activity in this catchment, could lead to an increase in the severity of flood events and soil erosion. Pine and eucalyptus –the main tree species in the basin– improve flood mitigation and control soil erosion (Carvalho-Santos et al., 2016a,b). These species are associated with a reduction in peak flows, mainly due to their growth rates and the ability of their canopy to intercept rainfall during the rainy season (Rodríguez-Suarez et al., 2014).

4. Conclusions

The SWAT model previously implemented for hydro-sedimentary study purposes in the Oka catchment was expanded to assess the separate and combined impacts of potential climate change and land cover scenarios on discharge, SPM and POC load. The first step was to test the robustness of the model to climate changes. The statistical criteria showed a satisfactory simulation, indicating that SWAT was fairly robust to climate changes and was appropriate for evaluating the impact of future climate on the catchment.

To assess climate change impacts, an ensemble with three GCMs (BNU_ESM, MPI_ESM_MR and MIROC_ESM), two RCPs (8.5 and 4.5), two downscaling methods (AN and SDSM) from CMIP5 until 2050 were considered. It found that the annual precipitation of the basin is likely to decrease by 27% in an RCP4.5 emission scenario and 28% in RCP8.5. The mean temperature will rise by ~1.6 °C in both scenarios. Seasonal and annual outputs from climate change projections found that under the same land cover conditions, the discharge, SPM and POC loads would decrease compared with the baseline period, as a consequence of precipitation decrease and ET increase.

In any work of this type, it is important to take into account the inherent uncertainties associated with climate projections, i.e. selection of climate model, downscaling method and greenhouse gas emissions. These uncertainties lie outside the scope of this work, however the uncertainty associated with hydrological modeling was controlled by applying the DSST through the aridity index and the GCMs were chosen with the climatic projections that best fit with the observed reference period. A complete assessment addressing a wider range of GCMs should therefore be considered.

The decrease in forest cover leads to a rise in raindrop erosive energy and a decrease in infiltration rate; when the infiltration capacity is exceeded, surface runoff occurs, which washes away soil particles. The trend in the results of forest clearcut scenarios showed that less forest lands for timber extraction results in more discharge through a reduction in ET and more SPM and POC loads.

The combined impacts showed little differences between scenarios with the same percentage of forest clearcut. The combined impacts of climate change and forest clearcutting on discharge, SPM and POC load showed the same downward trend given by climate change alone, but the percentage of change was not as severe, suggesting an offset from the increase in forest clearcutting which is more important than climate change.

Discharge is more sensitive to climate change than to changes in land cover. However, SPM and POC load are more sensitive to land cover than to changes in climate. SPM and POC loads are more affected than discharge in all separate and combined scenarios. Understanding the changes caused by the separate and combined impact of climate change and land use is crucial for sustainable water resource planning and management.

A temporal analysis at seasonal scale enables identification of variations in discharge, SPM and POC load that may occur throughout the year and which cannot be detected on an annual scale. Summer and spring are the seasons in which the decreases in discharge, SPM and POC load will be most severe.

This work provides useful information that may be used by decision-makers to design adaptive strategies, in terms of water quantity and quality, to address climate change threats in catchments in the Cantabrian region. In future work it would be important to assess the land cover and climate impacts with a focus on hydrological services, such as water timing, flood mitigation and water quality, provided by each land-use type present in the catchment. This is important within the context of the Water Framework Directive (WFD) for planning aimed at flood and drought risk management and mitigation.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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